National Aeronautics and Space Administration

UAS Integration into the NAS: HSI Display Evaluation Overview

Presented To: RTCA SC-228 DAA Working Group
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Overview

- Goal: Provide data on the effect of various Detect and Avoid (DAA) display and guidance features with respect to pilot performance of the self-separation function in order to determine the minimum information requirements for DAA displays
  - What configuration of display elements meets a minimum acceptable level of performance? What level of pilot maneuver guidance is required?
  - Definitions:
    - Informative: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. **No maneuver guidance or decision aiding is provided to the pilot**.
    - Suggestive: **Provides a range of potential resolution maneuvers to avoid a hazard with manual execution**. An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers.
    - Directive: **Provides specific recommended resolution guidance to avoid a hazard with manual or automated execution**. An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver.

Overview

- Approach: Conduct a series of iterative human in the loop experiments with different display configuration to objectively measure pilot performance on maintaining well clear
  - Key metrics: pilot response time, losses of well clear, severity of losses of well clear
  - Three simulations have been conducted: PT4, iHITL, PT5
    - Displays are modified/improved/changed based on data/observations
    - Displays are carried through to new HITLs to create anchors or linkages to previous data for comparison
    - New displays are developed for test
    - Test/simulation environment/protocols also updated and improved between HITLs

PT4 – Experimental Design

- Goal: Evaluate candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance.
  - What are the appropriate alerting thresholds for self separation?
  - What are the minimum information requirements for DAA displays?
  - Is there a performance difference between integrated and standalone displays?
  - What advanced display features improve pilot performance on maintaining well clear from other traffic?
- What advanced display features improve pilot performance on maintaining well clear from other traffic?
  - Experimental Design: Mixed Factorial Design
  - 2 (Display: Standalone, Integrated)
  - X 2 (Information: Basic, Advanced)
  - X 2 (Self-Separation Alerting Threshold)

PT4 – Overview

Part Task 4

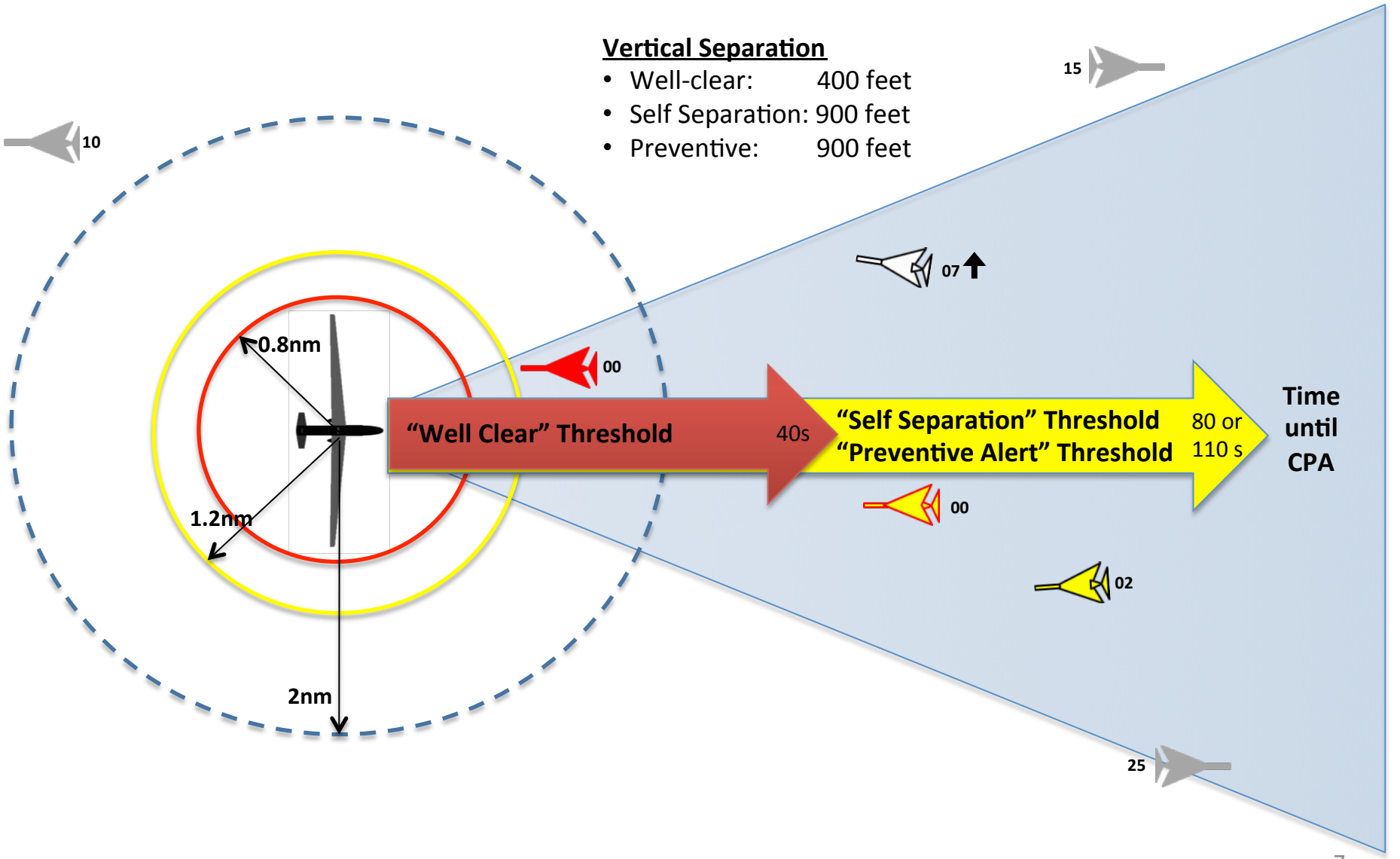
Integrated Basic (Minimum Information)	Integrated Advanced	Standalone Basic (Minimum Information)	Standalone Advanced

Display Types: Informative | Suggestive | Directive

PT4 – Information Level

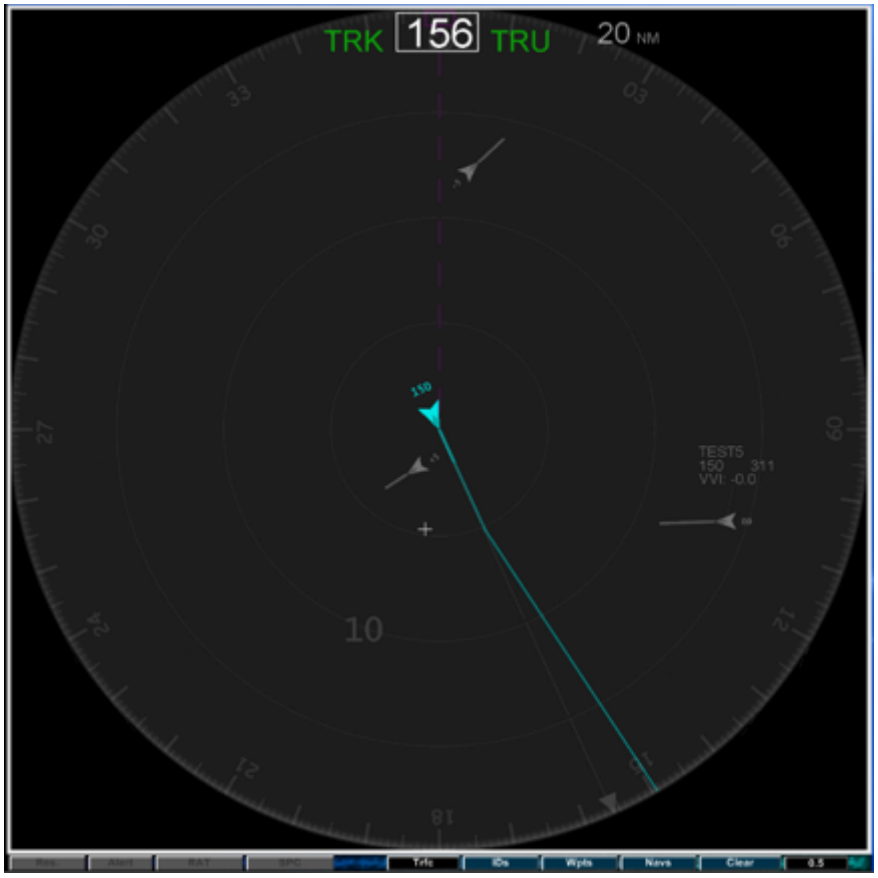
- Display Information Level: Basic versus Advanced
  1. Basic presents minimum information requirements only
     - Implementation identical as possible between Standalone and Integrated displays
     - Based on separate literature/requirements reviews by NASA and AFRL HMI teams
     - Vetted with FAA tech center (based on study they were running)
     - Similar to DO-317B (was a source document)
     - Alerting considered part of the min set
  2. Advanced information elements:
     - Implementation different between Standalone and Integrated displays
     - Additional alerting information (predictive CA)
     - Time to and location of predicted CPA (intruder and ownship)
     - Pilot guidance
       - Trial/vector planner (suggestive)
       - Maneuver recommendations (directive)
     - Vertical situation display (Integrated only)

Alerting Criteria

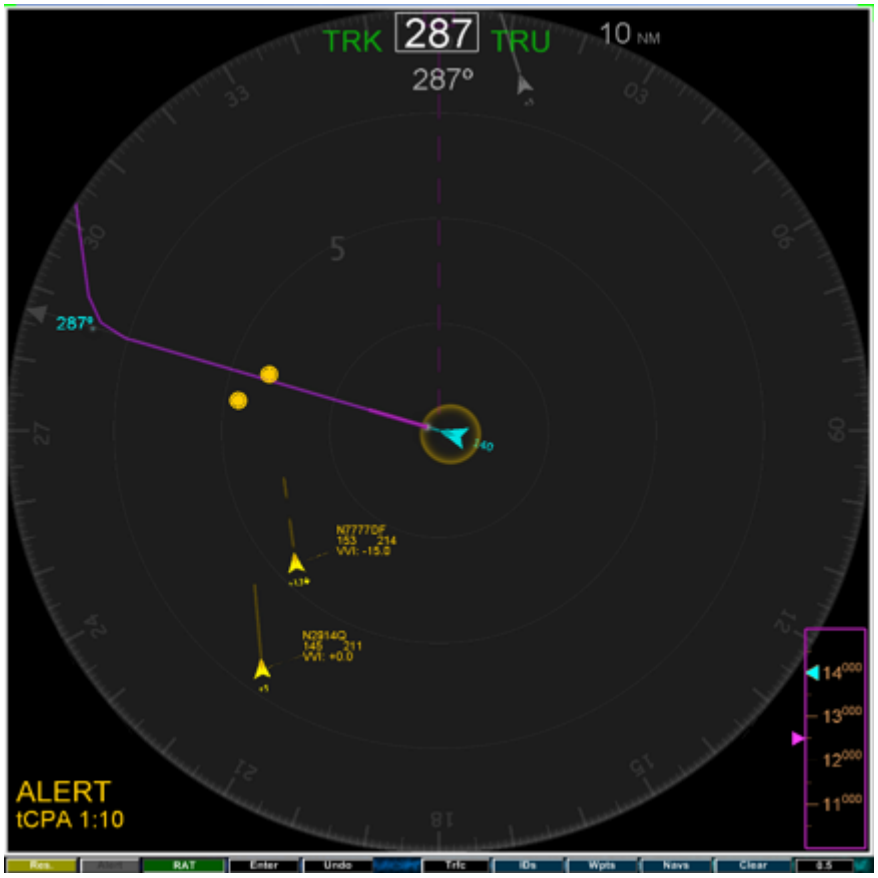


PT4 – Standalone Displays

Basic



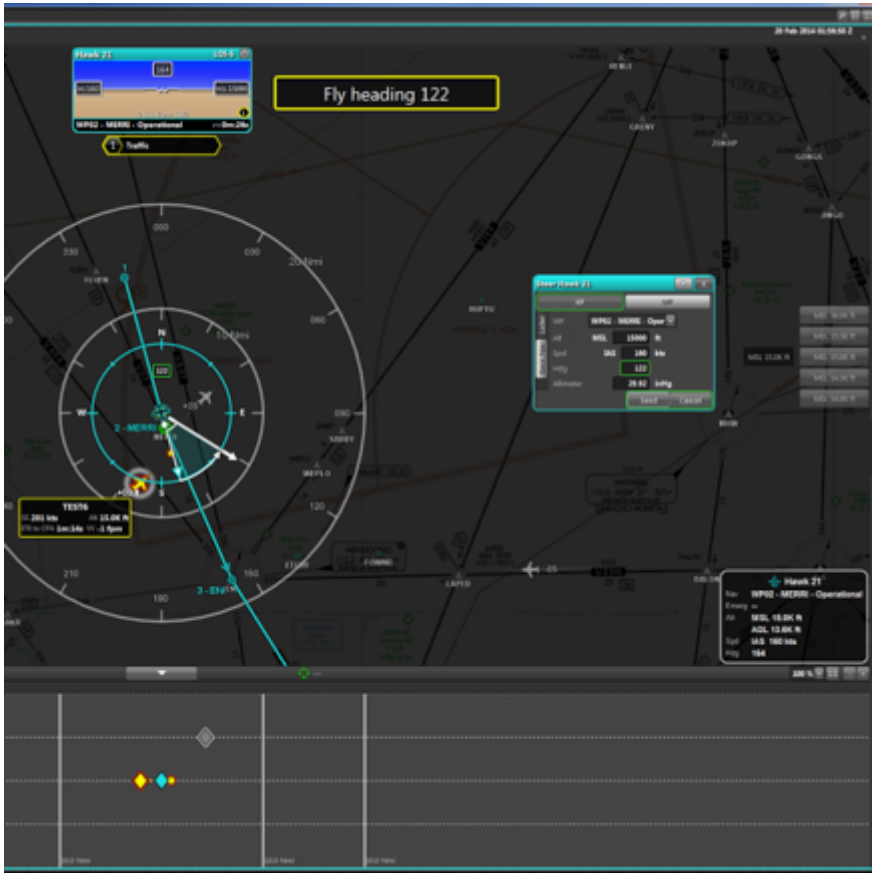
Advanced



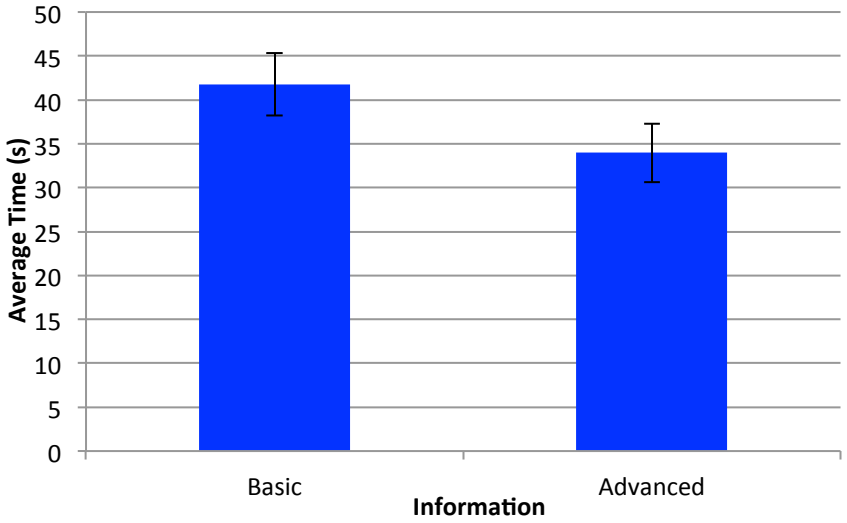
PT4 – Integrated Displays

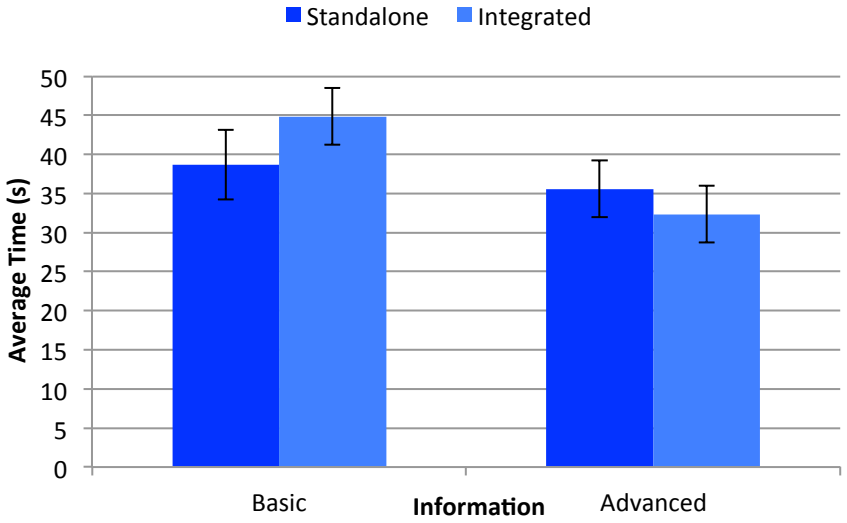
Basic

Advanced



PT4 – Total Response Time Results

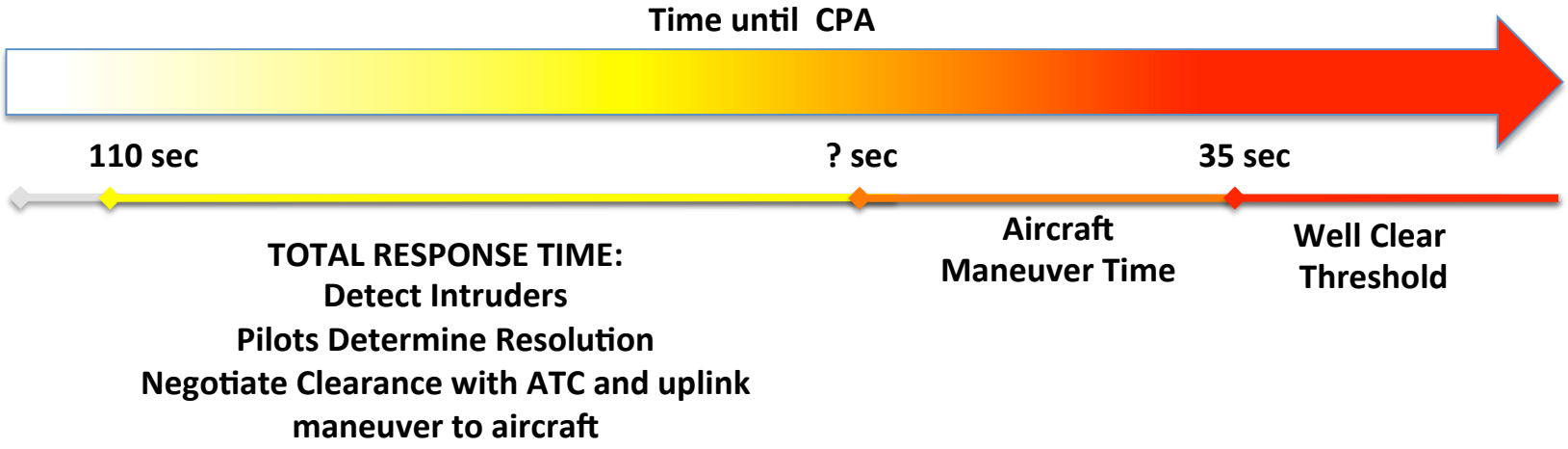




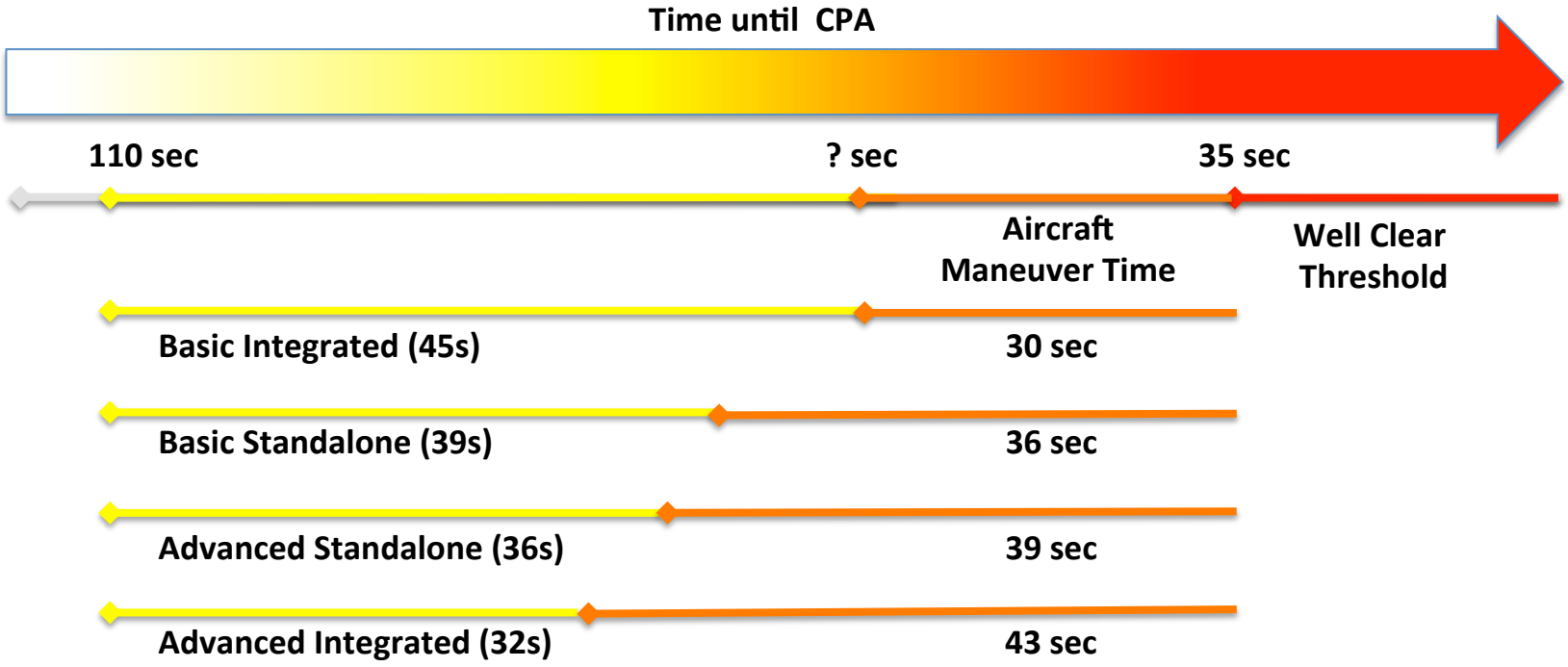
- There was a significant main effect of Information on Total Response Time, $p < .05$
  - Advanced was significantly faster (by 13.79 seconds on average) compared to Basic
- Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
  - Basic = 47.77 sec
  - Advanced = 33.98 sec

- There was not a significant interaction of Information by Display for Total Response Time, $p > .05$
- Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
  - Basic Standalone = 38.68 sec
  - Basic Integrated = 44.86 sec
  - Advanced Standalone = 35.60 sec
  - Advanced Integrated = 32.35 sec

Self-Separation Timeline

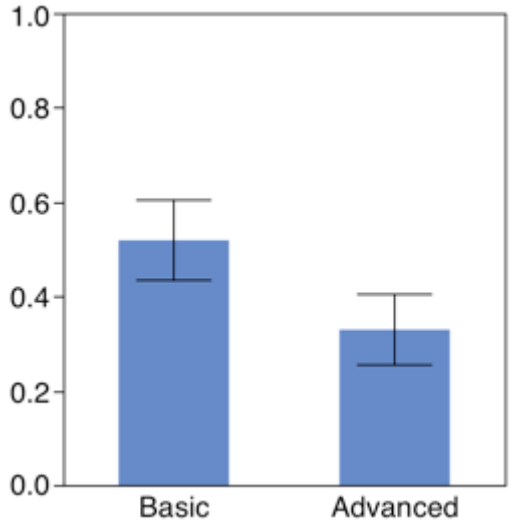


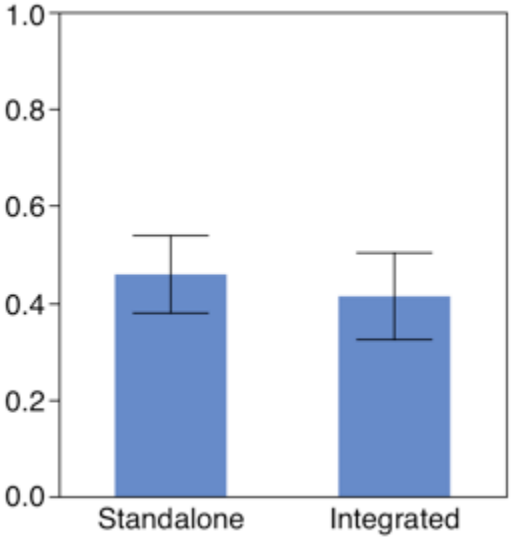
PT4 – Response Time Results

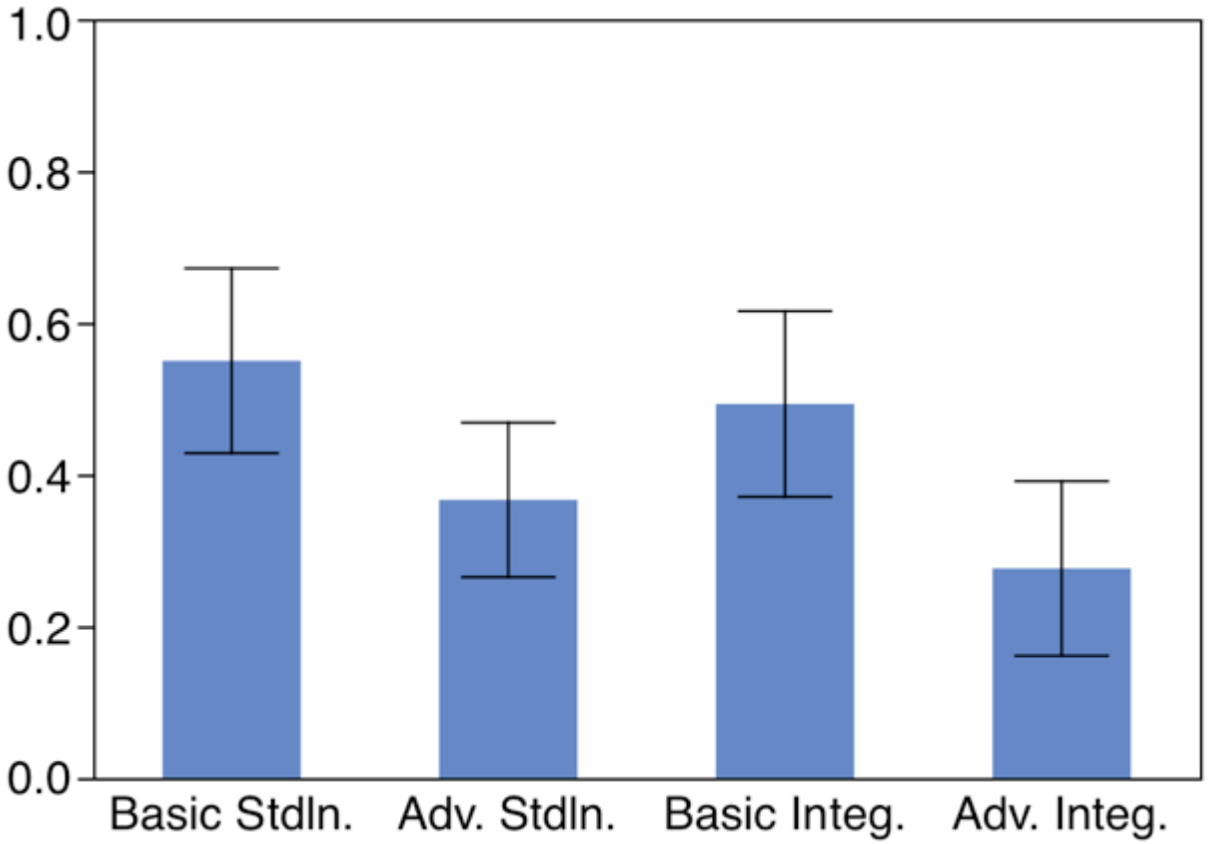


PT4 - WCVs

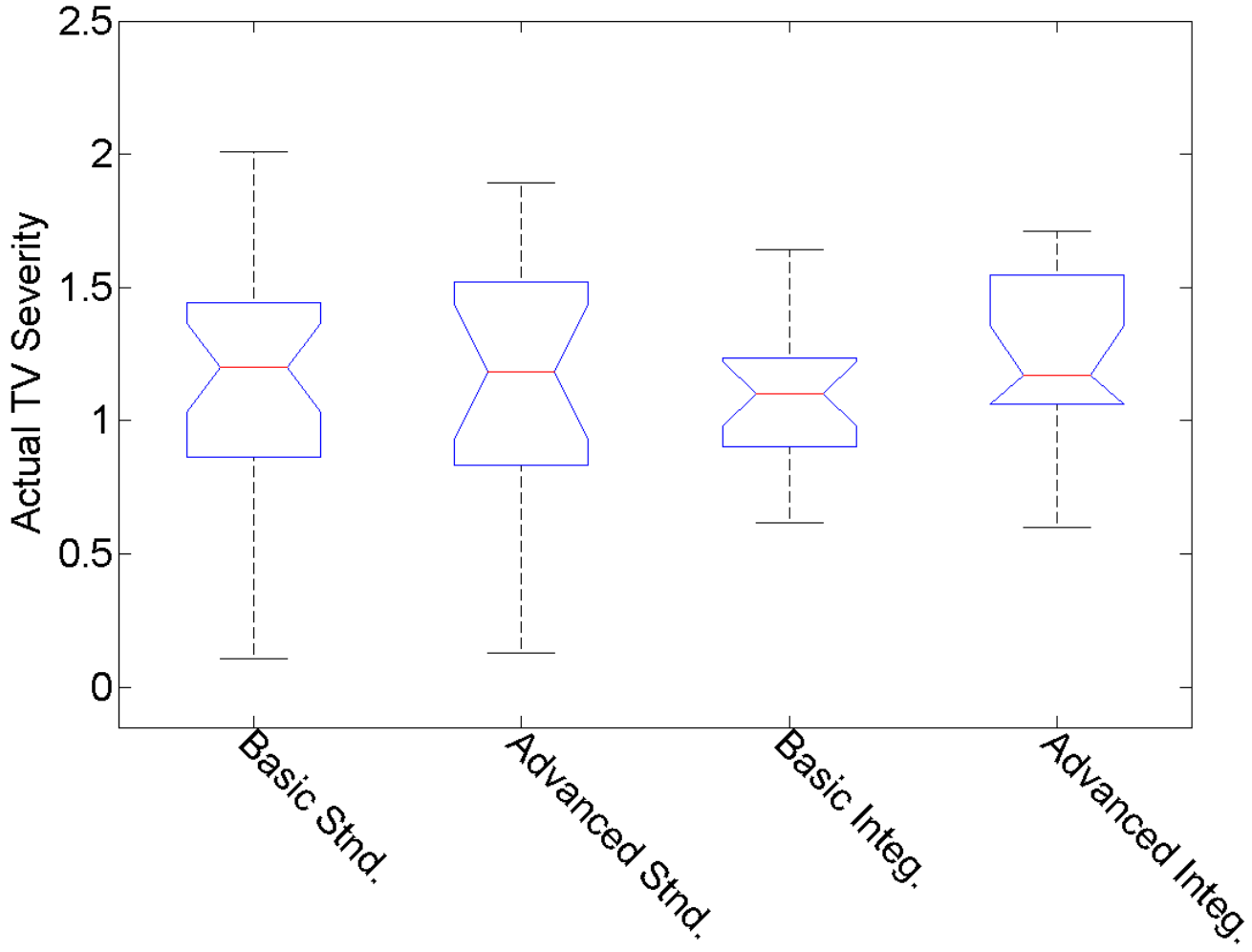
Proportion of Losses of Well Clear







PT4 – WCV Severity



PT4 – Results Summary

- Consistent advantage seen for Advanced over Basic displays in pilot response times
  - Overall, the Advanced displays had a faster Total Response Time (from initial alert appearance to the final maneuver upload) compared to Basic (14s faster, on average)
- There were no significant differences between the Standalone and Integrated condition
- No significant differences in number of, or severity of, losses of well clear, however:
  - Advanced had lower rates of LoWC than basic
  - No difference between Standalone and Integrated in rates of LoWC
  - Severity of well clear about the same across all displays

iHITL – Experimental Design

- Goals:
  1) Determine the individual contributions of the various PT4 advanced display features to pilots' response times and ability to maintain well clear
  2) Introduce non-cooperative intruders to examine effect of different sensor ranges on pilots ability to maintain well clear
- One-Way Repeated Measures Factorial: Display Information Level (4 Level; Within Subjects)
  - D1: Advanced Display with Information Only **(Informative)**
  - D2: Advanced Display with Information + Vector Planner **(Suggestive)**
  - D3: Advanced Display with Information + Auto Resolutions **(Directive)**
  - D4: Advanced Display with Information + Vector Planner + Auto Resolutions **(Suggestive + Directive)**
    - Roughly same as 'Advanced' suite in PT4

iHITL – Overview

Part Task 4

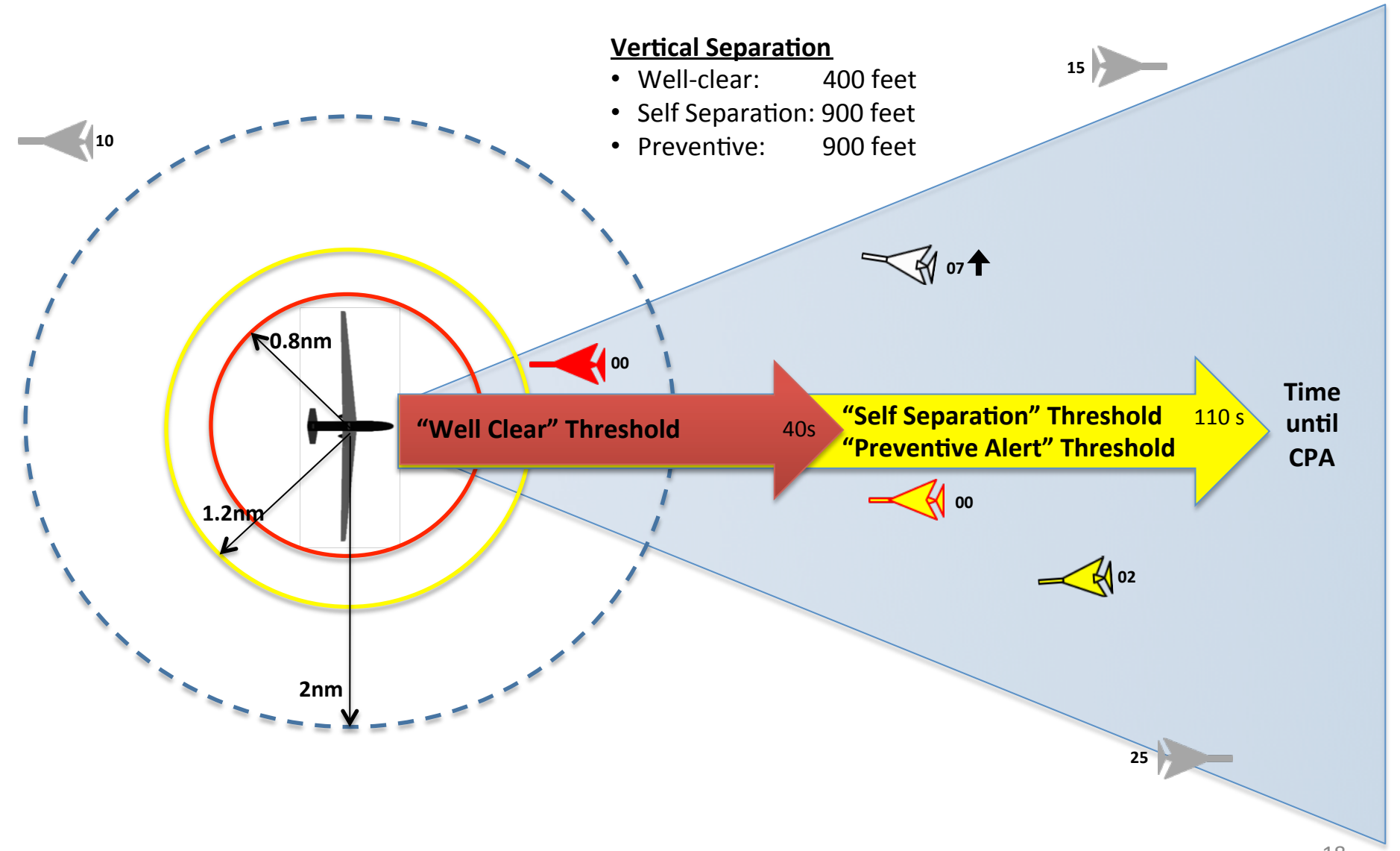
Integrated Basic (Minimum Information)	Integrated Advanced	Standalone Basic (Minimum Information)	Standalone Advanced

Integrated HITL

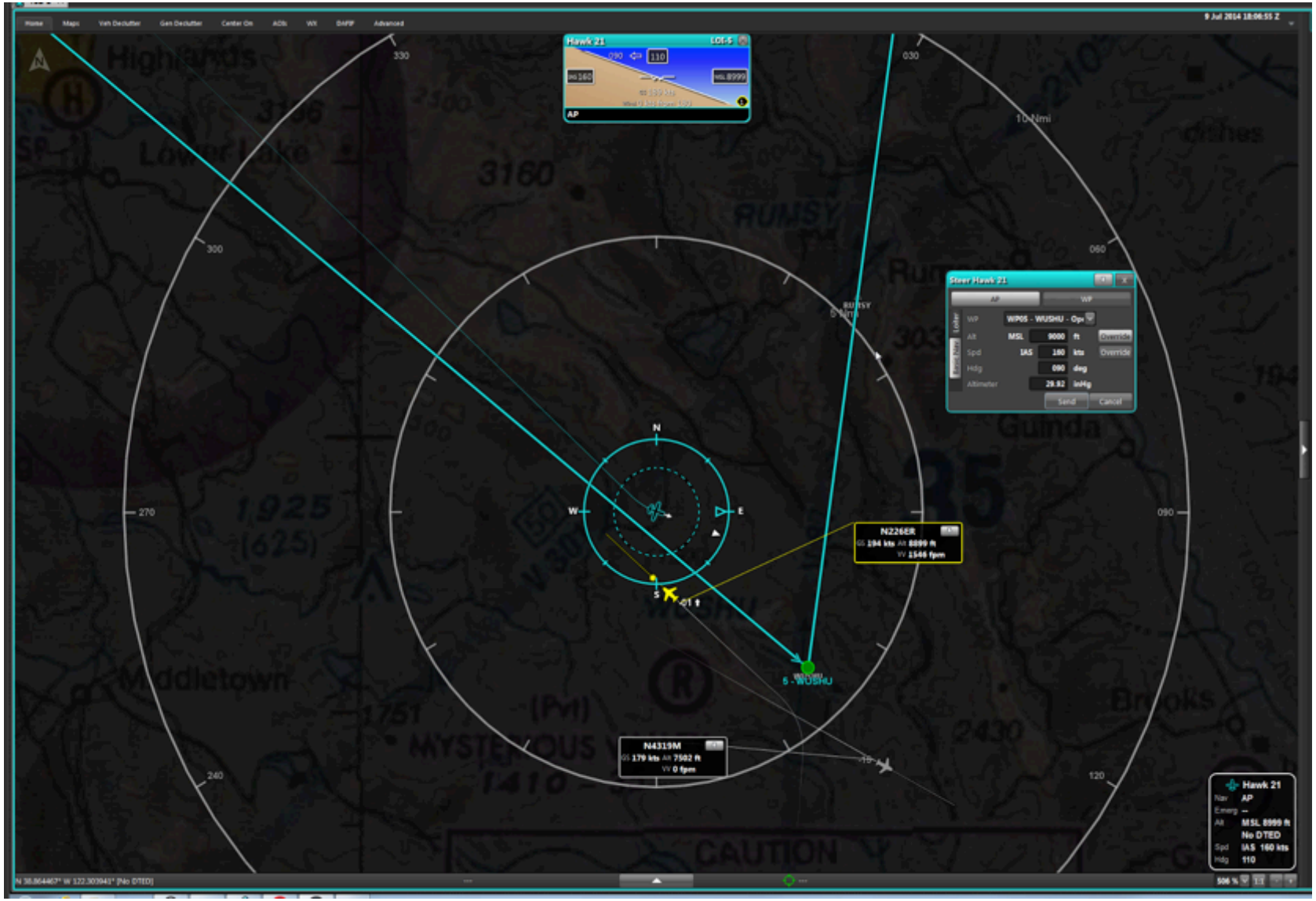
Advanced Information Only	Advanced Information + Vector Planner	Advanced Information + Auto Resolutions	Advanced Information + Trial Planner + Auto Resolutions

Display Types: Informative | Suggestive | Directive

iHITL – Alerting Criteria



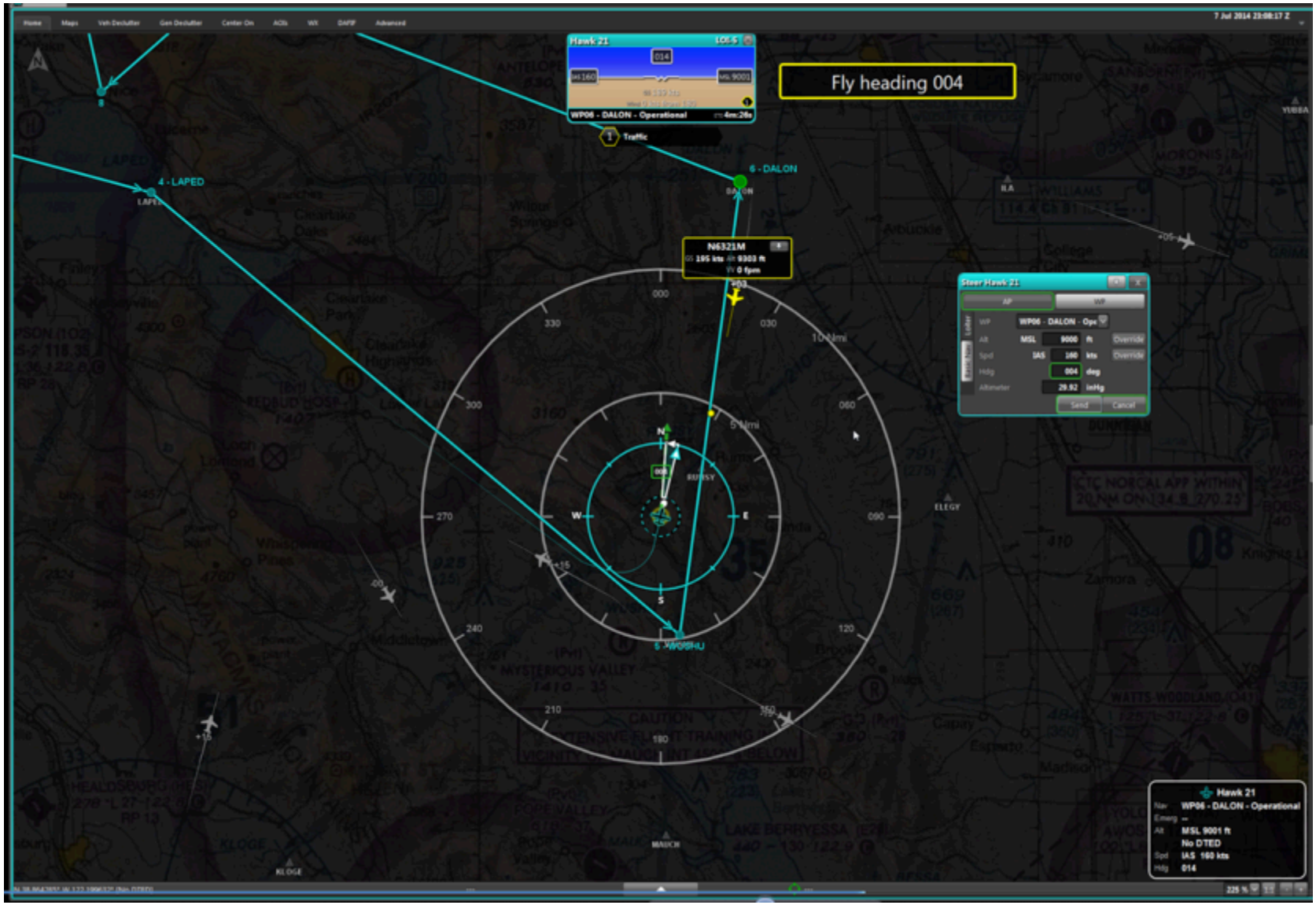
iHITL – D1


Hawk 21
AP
Steer Hawk 21
WP05 - WUSHU - Ops
MSL 9000 ft
IAS 160 kts
090 deg
29.92 inHg
Send
Cancel
N226ER
194 kts Alt 8899 ft
VV 1548 fpm
N4319M
179 kts Alt 7502 ft
VV 0 fpm
5 - WUSHU
Hawk 21
AP
MSL 8999 ft
No DTED
IAS 160 kts
110
10 Nmi
CAUTION

iHITL – D2


Hawk 21
WP03 - Operational
SABBY
10 - SABBY
2 - WEPLO
4 - LAPED
MSL 7000 ft
No DTED
IAS 160 kts
121

iHITL – D3

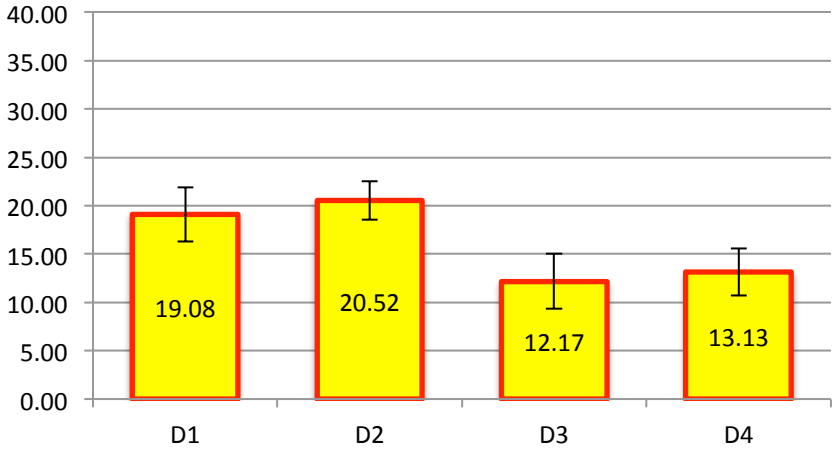

Fly heading 004
4 - LAPED
6 - DALON
N6321M
WP06 - DALON - Operational
Steer Hawk 21
Hawk 21
WP06 - DALON - Operational
MSL 9001 ft
No DTED
IAS 160 kts
014

iHITL – D4


Fly heading 110
10 - SABBY
2 - WEPLO
4 - LAPED
6 - DALON
8 - WUSHU
N991KE
Steer Hawk 21
WP05 - WUSHU - Ops
MSL 7000 ft
IAS 180 kts
110 deg
29.92 inHg
Send
Cancel
Override
Hawk 21
WP05 - WUSHU - Operational
1 Traffic
123 kts 7384 ft
-500 fpm
MSL 7384 ft
No DTED
GS 123 kts
VSCS-OFFGCS-VSCS.Track.0008
FIXED WING
Friend (F)

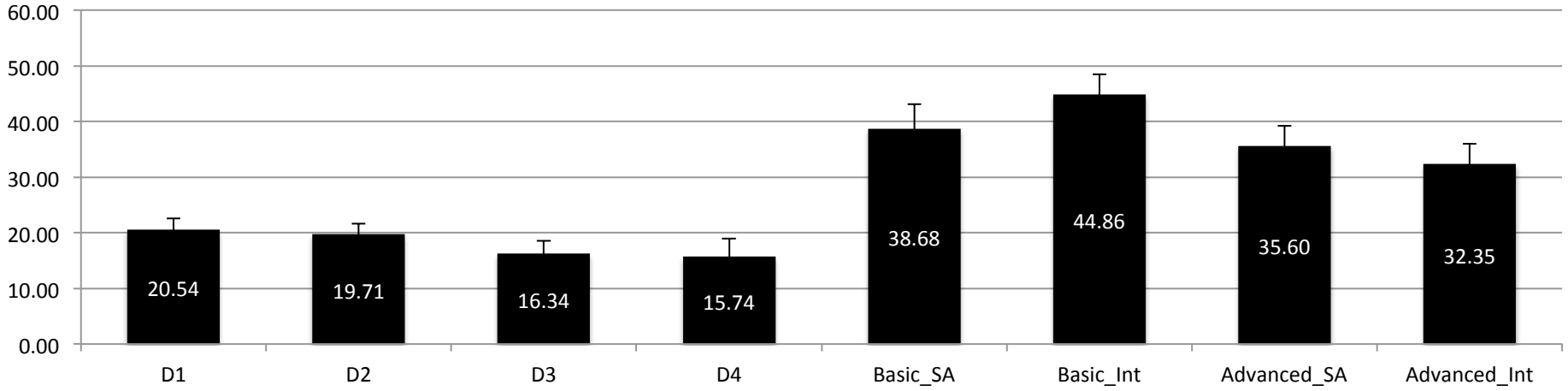
iHITL – Response Time Results

Predictive SS Alerts

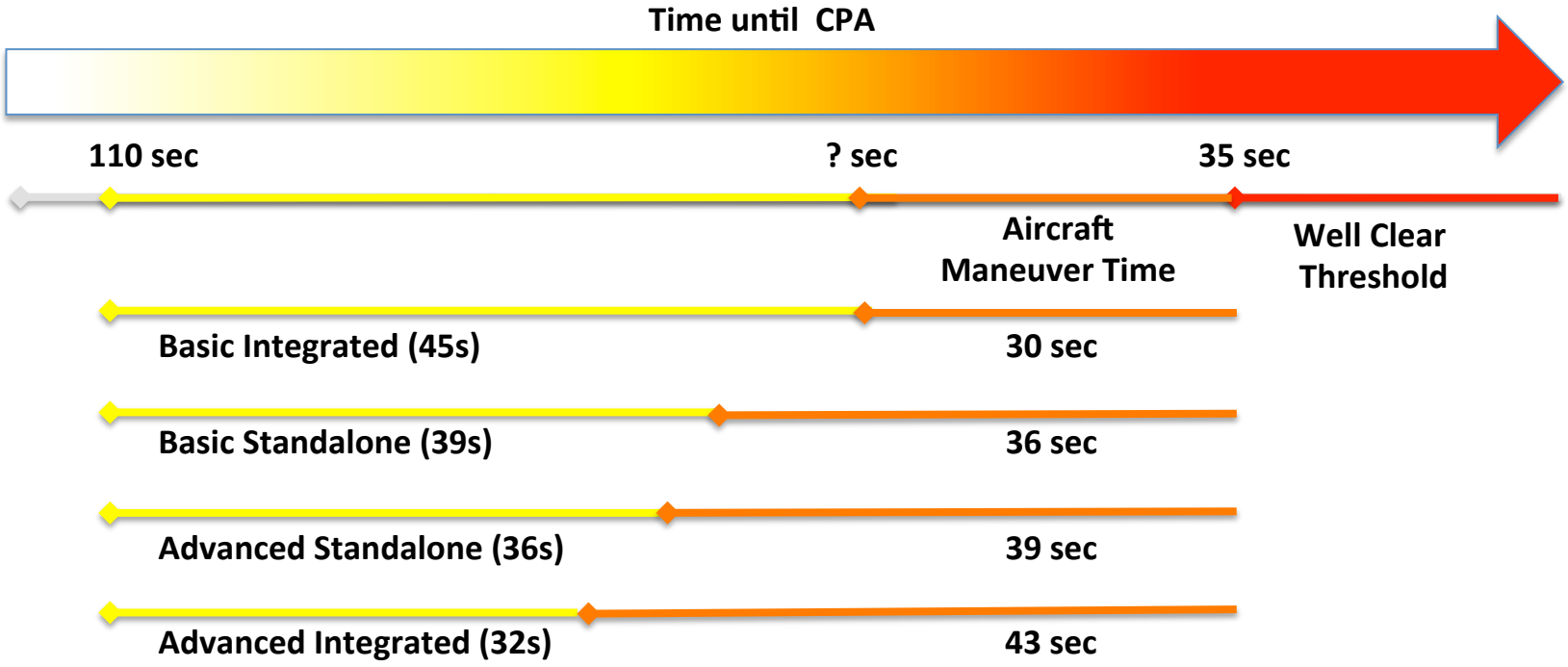


- Predictive SS = encounters that are predicted to lose well clear at any point during the encounter
- There was a near significant effect of Display on Total Response Time for Predictive SS alerts, p = .056
- Pilots took an average of **16.22 seconds** to complete their final edit in response to Predictive SS alerts (from first alert appearance)

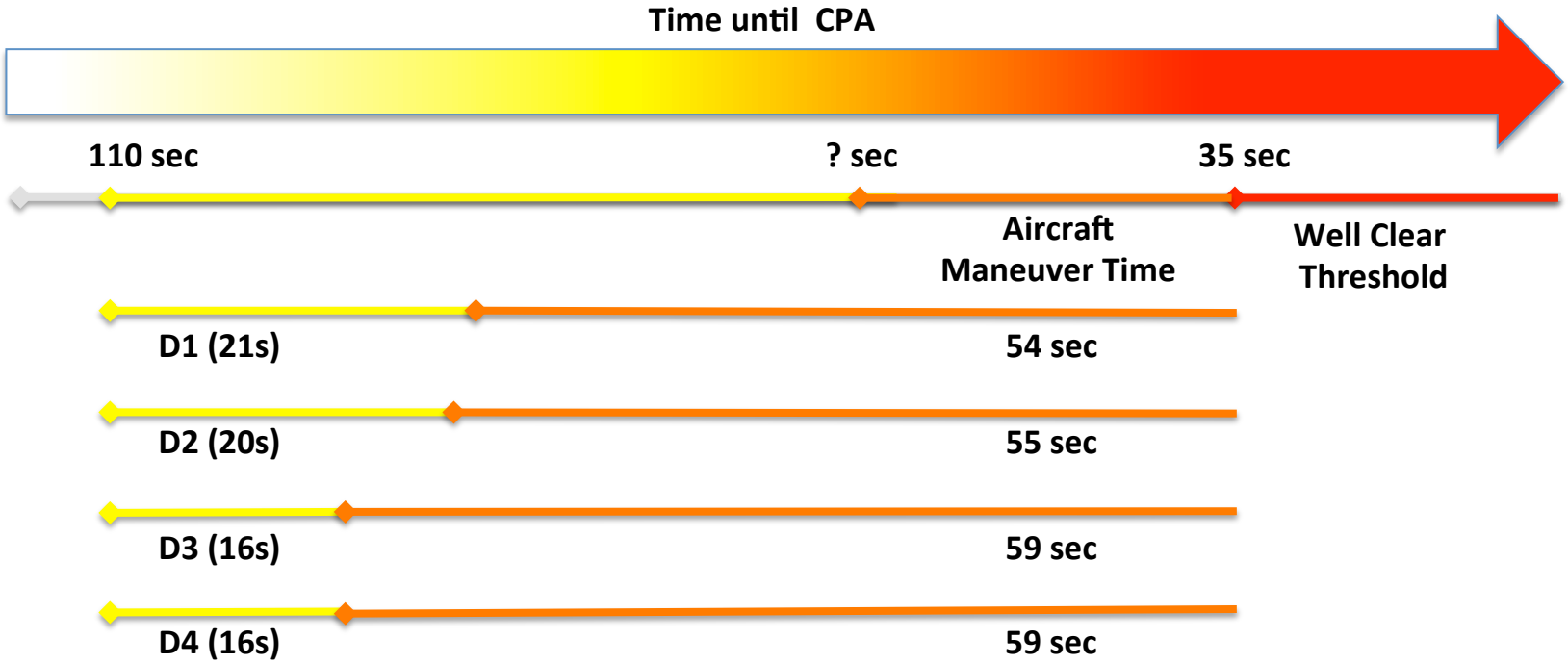
IHITL and PT4 Display Comparison (All Encounters)



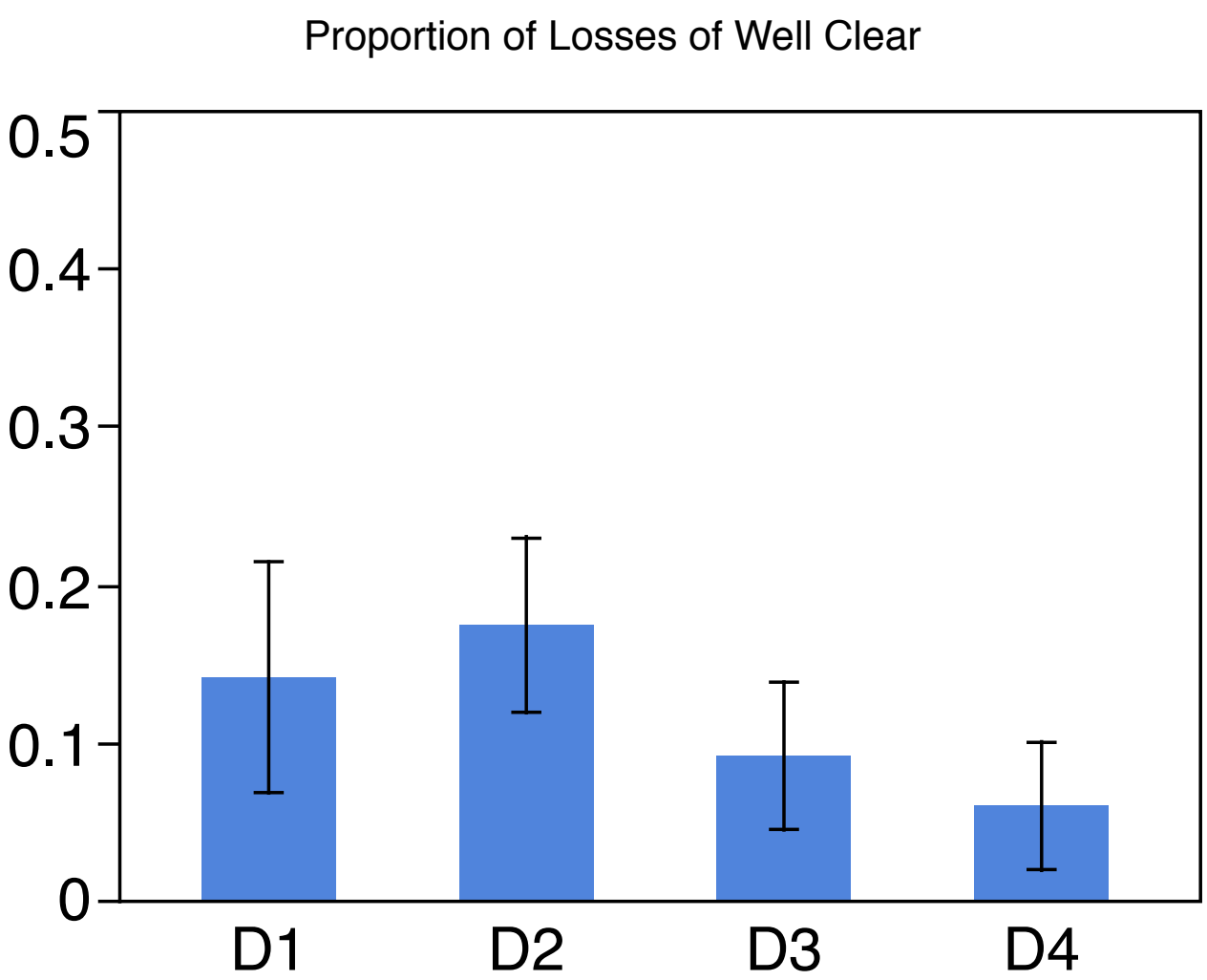
PT4 – Response Time Results



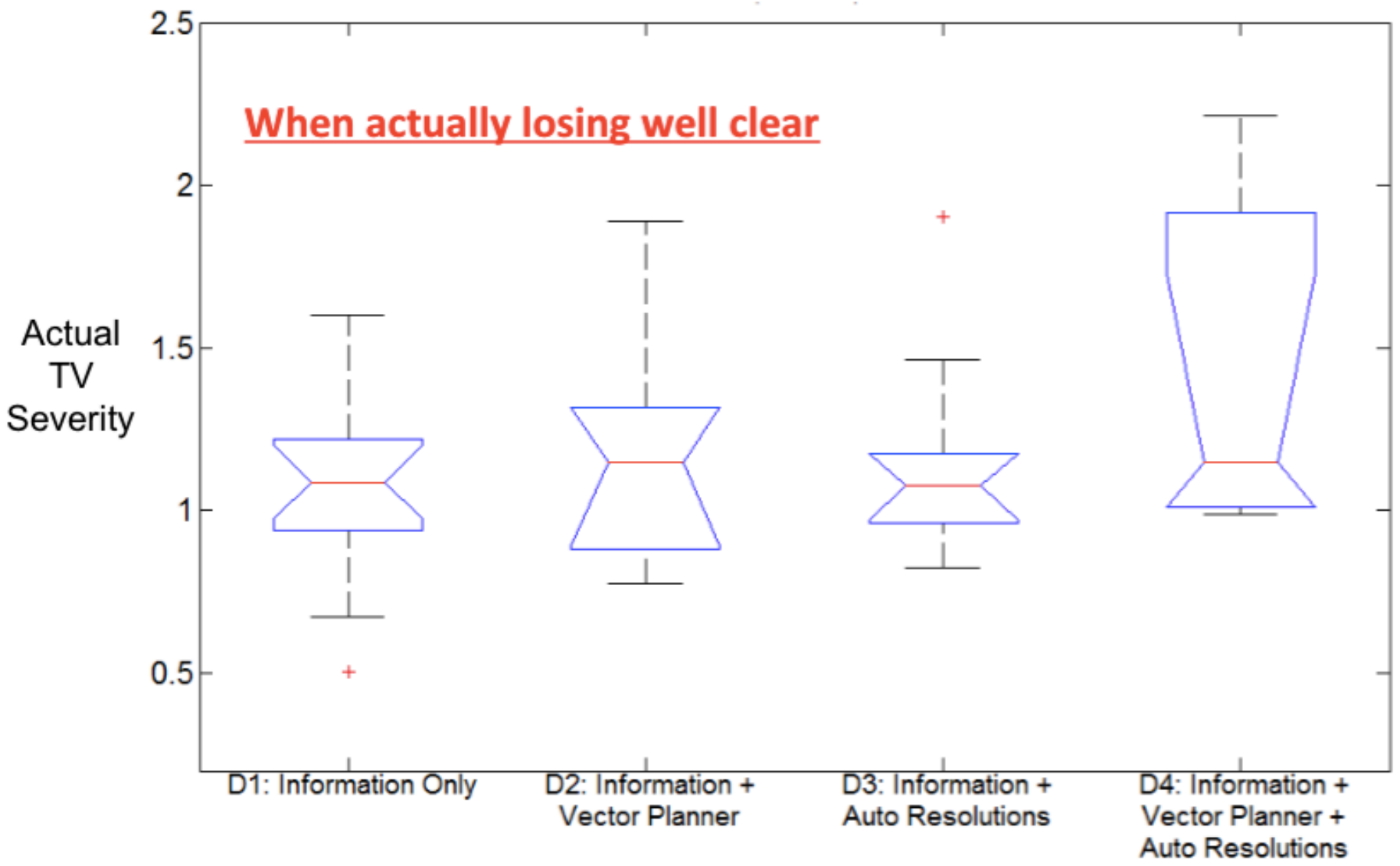
iHITL – Response Time Results



iHITL - LoWC



iHITL – LoWC Severity



iHITL – Results Summary

- Total Response Time:
  - No significant differences between displays
  - Trend shows **Directive Only** and **Suggestive + Directive** as faster than Information Only and Suggestive Only
- Well Clear Metrics:
  - No significant differences between displays
  - **Information** and **Suggestive Only** (D1 and D2) display conditions had 2.5X as many LoWCs than the **Suggestive + Directive** combined (D4)
  - Severity data shows evidence of trends toward performance benefits with **Suggestive + Directive** compared to other three displays
- **What does this mean for minimum information requirements??**

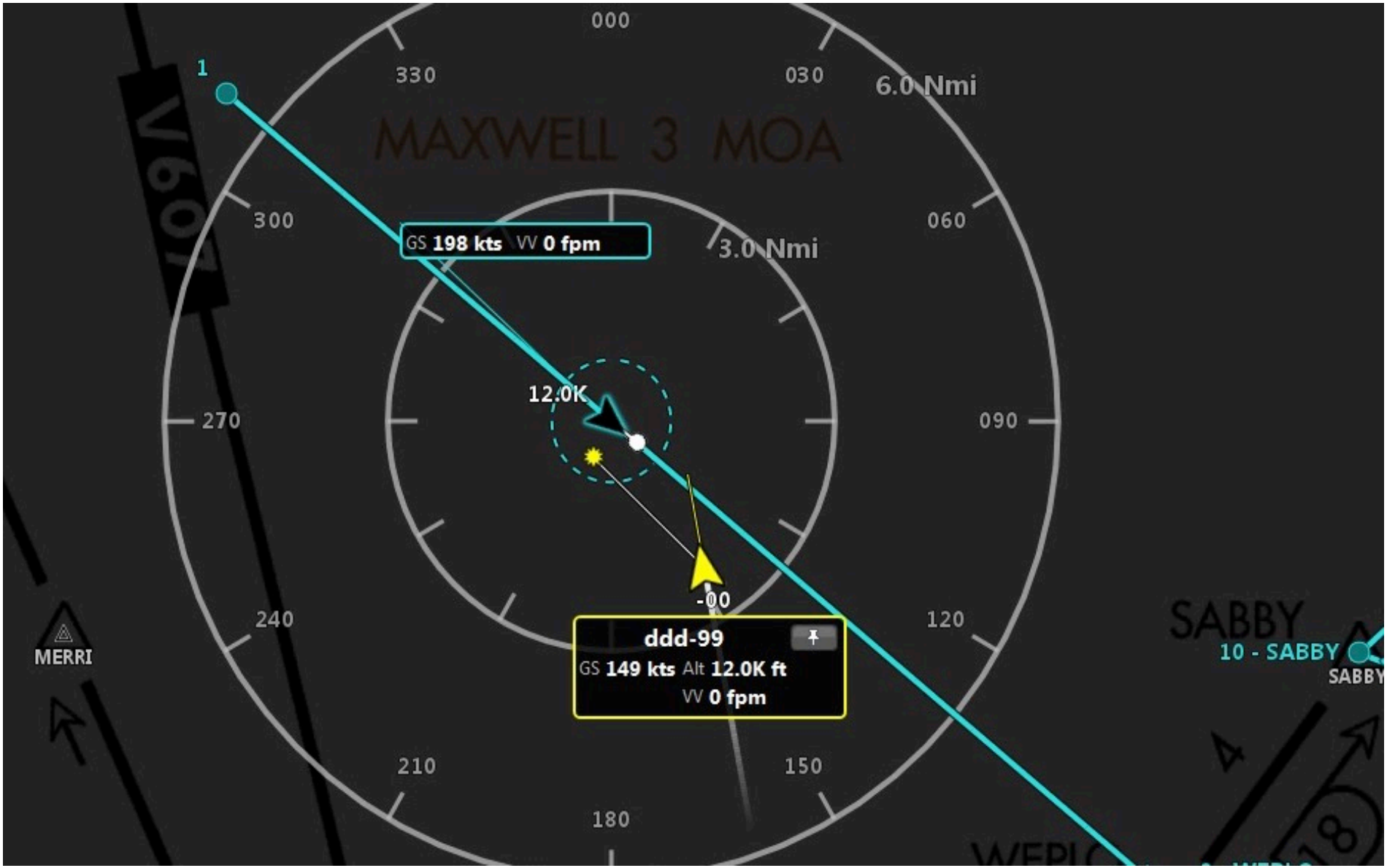
PT5 - Overview

- Goal: Continue evaluation of candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance to inform SC-228 DAA Minimum Operational Performance Standards
- Method:
  - Build upon results of previous hitl simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
    - PT4: Advanced better than Basic (but issues; well clear & display training, pop-ups)
    - iHITL: No significant differences between Advanced information features from PT4, but trends favoring combined **Suggestive + Directive (D4)** guidance
    - Maneuver Study: Banding display showed faster response time compared to informative and directive displays; banding and advanced informative had least losses of well clear (neither results statistically significant)

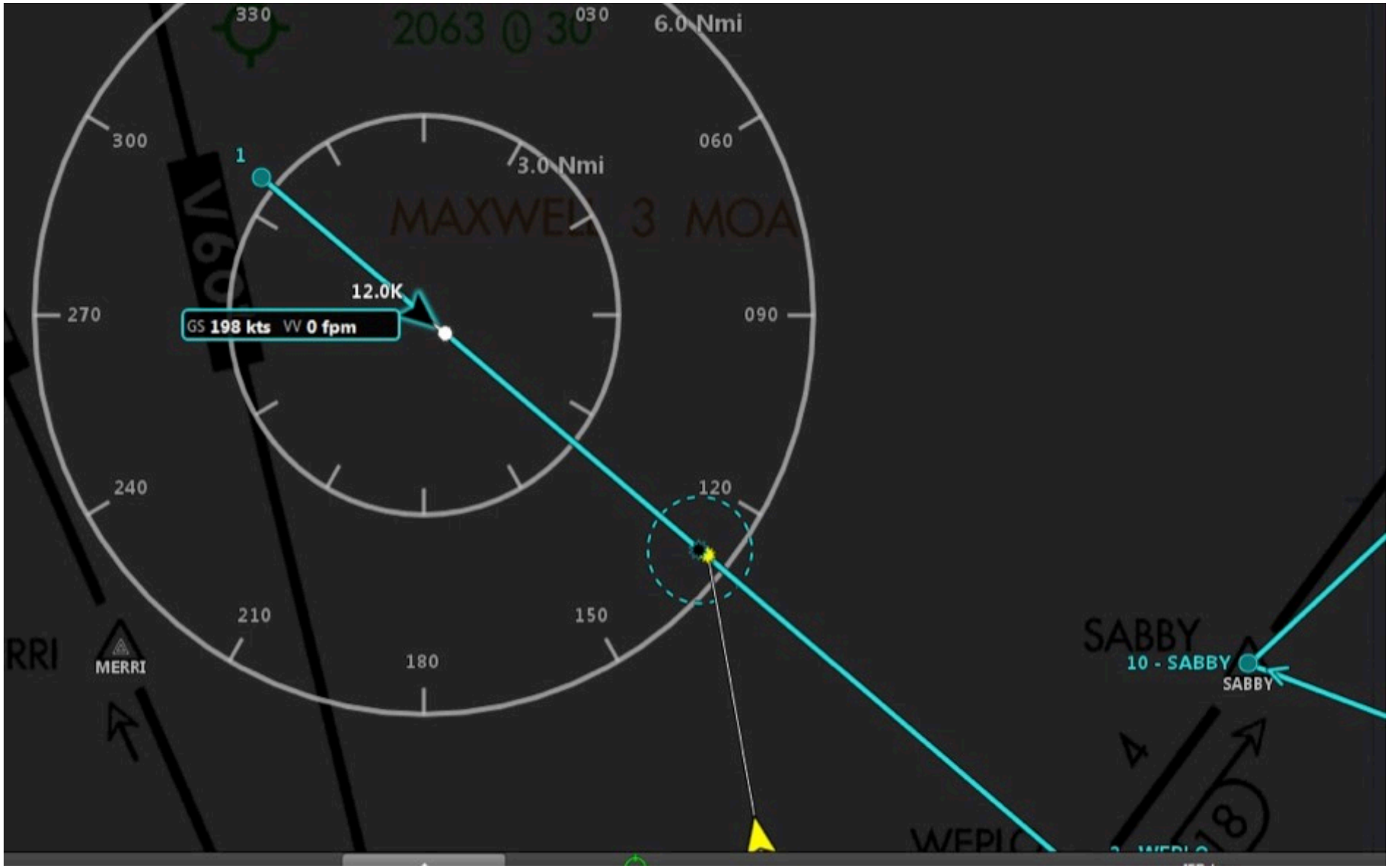
PT5 – Proposed Experimental Design

- Can test up to four displays in a HITL
- Assume Directive Only not min requirement for MOPS
- Candidate displays for PT5
  - Informative:
    - Minimum Information (rerun from PT4 with updated alerting scheme)
    - Advanced Information (iHITL D1)
    - Relative Vector Display (based on Garmin)
    - Translated Well Clear Ring
  - Suggestive:
    - Vector Planner (iHITL D2)
    - Stratway+ Banding
    - JADEM Banding (same underlying algorithm as Vector Planner)
  - Suggestive + Directive:
    - Vector planner + Resolutions (iHITL D4)
    - Banding + Resolutions

PT5 – Relative Vector Display



PT5 – Translated Well Clear



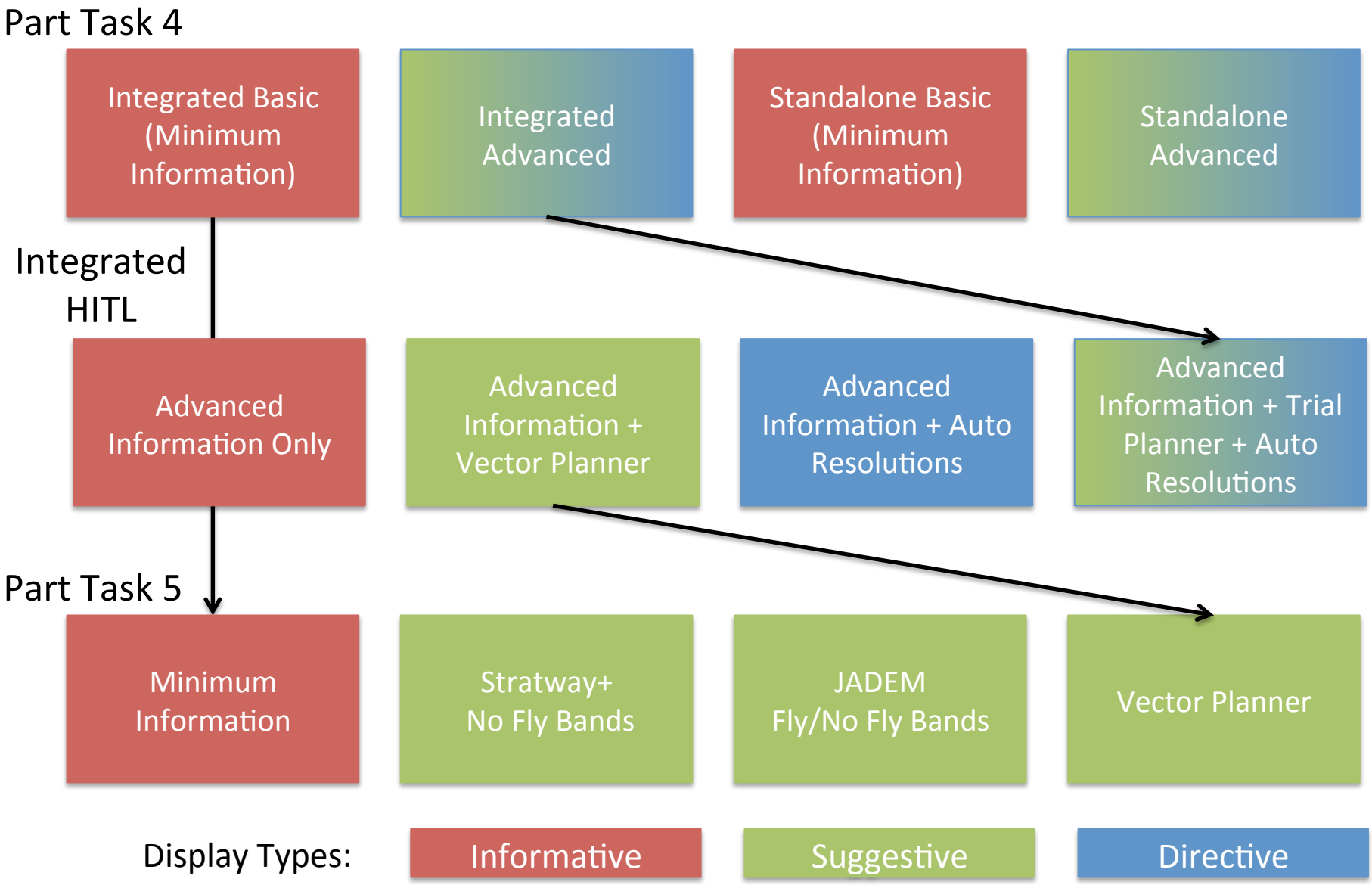
PT5 – Proposed Experimental Design

- Decisions:
  - Eliminated Suggestive + Directive options to focus on Informative and Suggestive Only displays
  - Prototyped and eliminated Relative Vector and Translated Well Clear Ring
    - Concerns for multiple intruder encounters in terms of potential clutter, prioritization of intruders and ambiguity of potential safe maneuvers
    - Informative display concepts inherently difficult to design to support mathematically complex well clear definition – use of automation to do the math makes most sense
  - Chose minimum information display as baseline (and verification of results from PT4)
  - Chose Vector Planner to baseline to iHITL
    - To be modified to be less integrated with the auto pilot and more equal to bands displays
  - Chose Stratway+ and JADEM bands displays
    - Bands showed performance benefits in Manevuer study
    - Different presentation of suggestive display guidance
    - Stratway+ and JADEM bands have different approaches (No Fly versus Fly/No Fly)
    - JADEM uses same algorithm as Vector Planner (so results are directly comparable to previous HITLs)

PT5 – Final Experimental Design

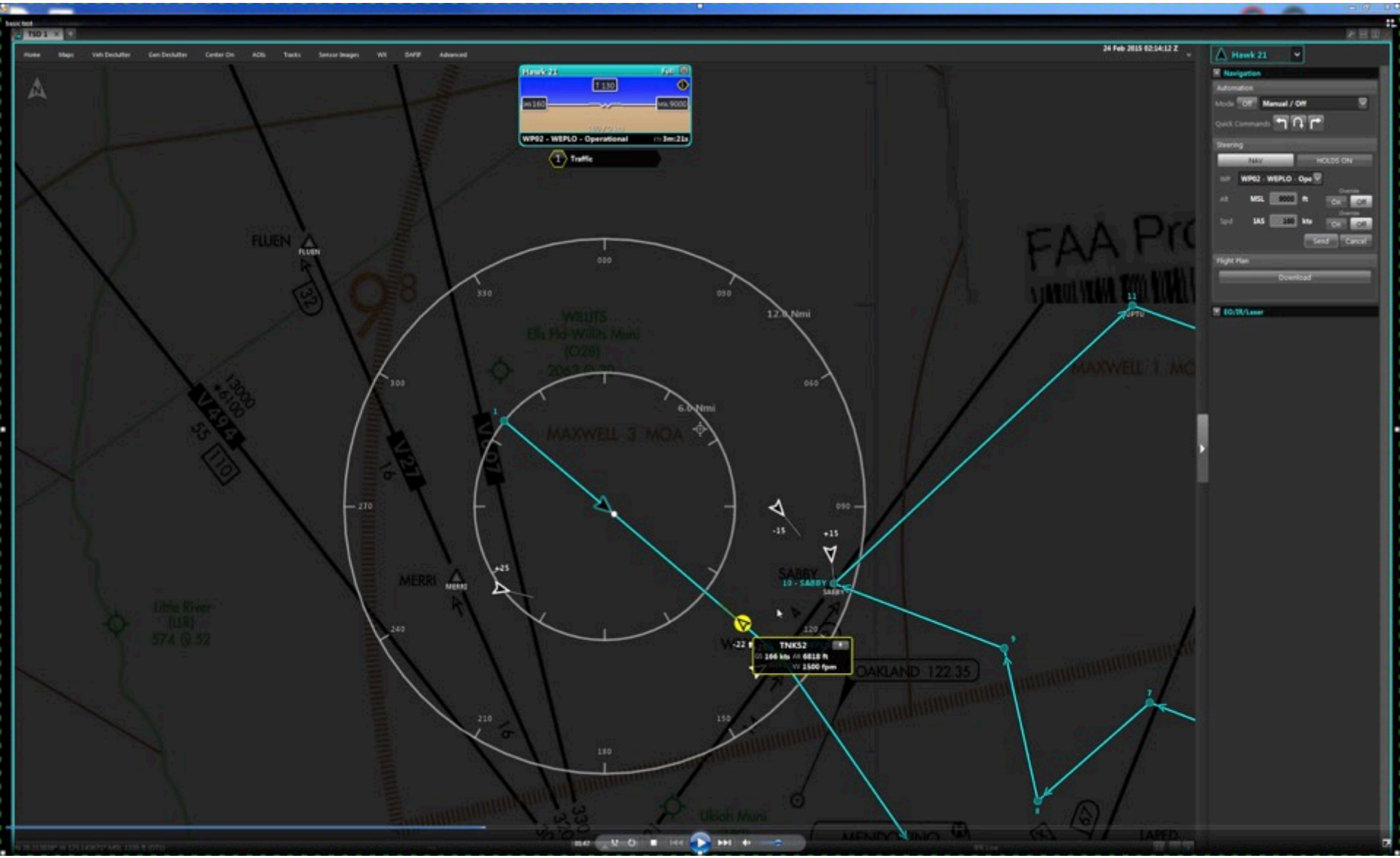
- Mixed Factorial Design – 2 variables of interest:
  - Display Configuration (Within Subjects Independent Variable):
    - Display 1: Minimum Set
    - Display 2: Stratway+ No Fly Bands
    - Display 3: JADEM Fly/No Fly Bands
    - Display 4: JADEM Vector Planning Tools
  - Surveillance Performance (Between-Subjects Independent Variable)
    - Level 1: Perfect Surveillance Data
    - Level 2: Imperfect Surveillance Data

iHITL – Overview



Alert Level	Name	Pilot Action	DAA Separation Criteria	SST (Time Until Penetrating Separation Criteria)	Symbology	Aural Alert Verbiage
4	Self Separation Warning Alert	Immediate action required to avoid a well clear violation, notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA equivalency: 60 sec)		“Traffic, Maneuver Now”
3	Corrective Self Separation Alert	Action to remain well clear will be necessary if the encounter does not change, coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	75 sec (TCPA equivalency: 110 sec)		“Traffic, Separate”
2	Preventive Self Separation Alert	Action to remain well clear will be necessary only if one or both aircraft make both a horizontal and vertical maneuver, do not climb/descend or turn into the intruder and be prepared to respond if the intruder begins climbing/descending or turning towards you. You may want to coordinate with ATC about the intentions of the intruder.	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	75 sec (TCPA equivalency: 110 sec)		“Traffic, Monitor”
1	Self Separation Proximate Alert	No action necessary to avoid this aircraft, but its presence should be considered when determining a resolution maneuver to avoid other aircraft.	DMOD = 0.75 nmi HMD = 1.5 nmi ZTHR = 1200 ft modTau = 35s	85 sec (TCPA equivalency: 120 sec)		N/A
0	None (Target)	No action necessary, There is an aircraft within your sensor range, but it is not expected to present a threat.	Within surveillance field of regard	X		N/A

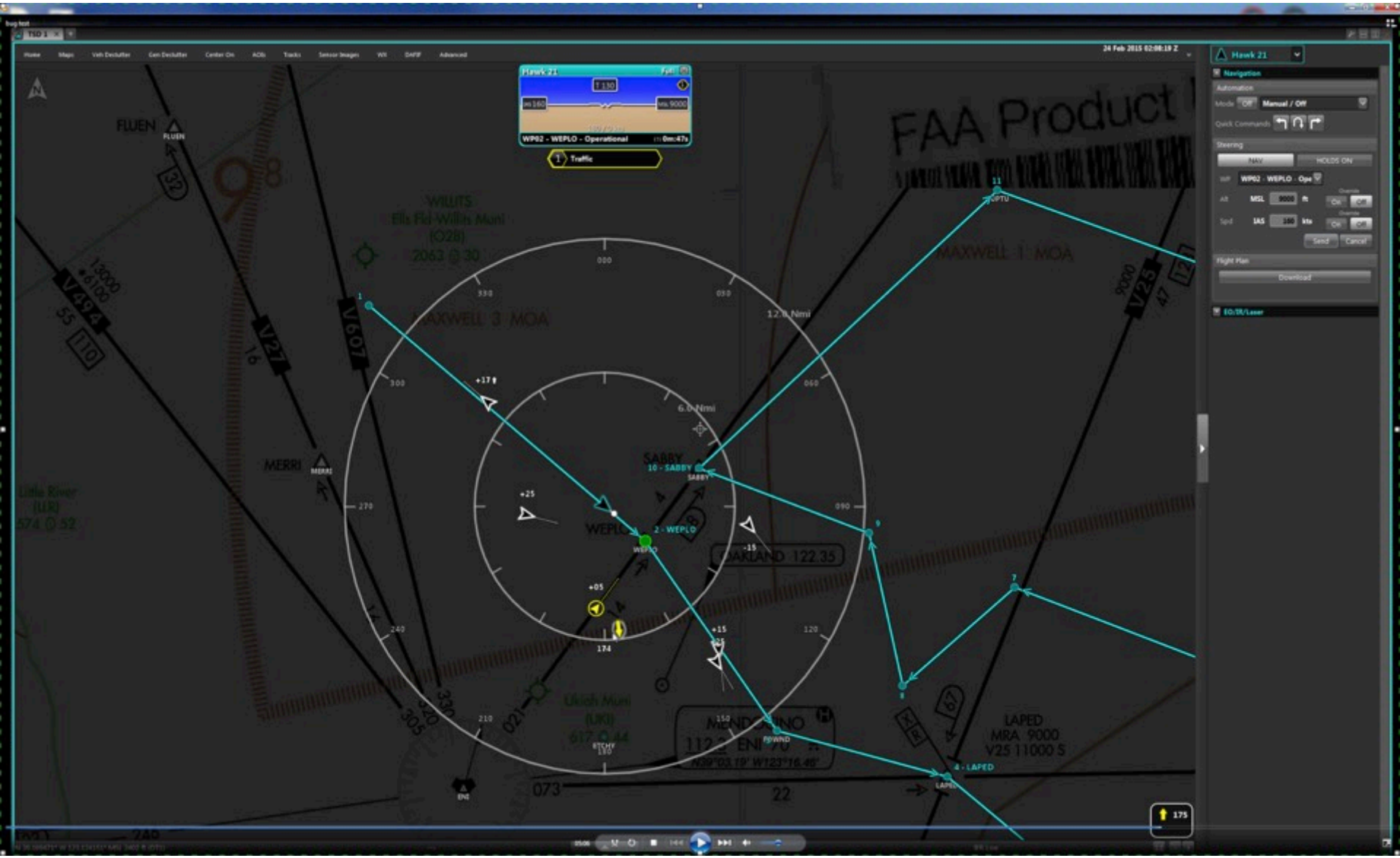
Display 1: Min Info



Display 2: Stratway+ No Fly Bands

Display 3: JADEM Fly/No Fly Bands

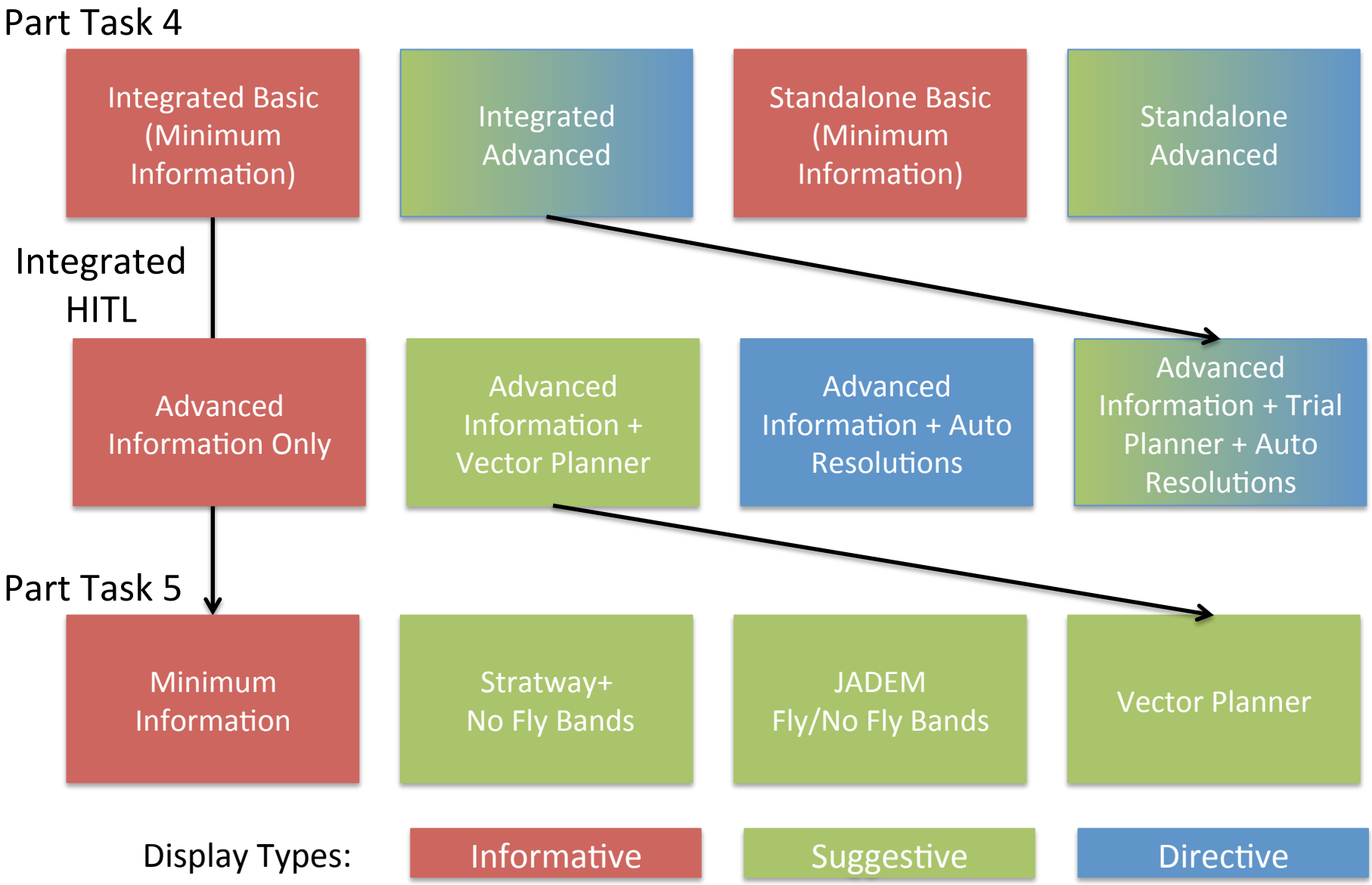
Display 4: Vector Planner



Flight Test 3

- Full Mission Configuration (Aug/Sept) will allow for verification of pilot performance results from HITLs in live flight environment with live intruders
  - Maintain as many of the test conditions constant
    - GCS (with surrogate)
    - Mission profile & pilot tasks
    - Airspace & ATC
  - Real world uncertainty
    - Real sensors (ADS-B)
    - Real control delay
- Can test up to three displays
  - Will be any three that have already been developed and tested in HITLs, with minor modifications
  - Decision to be made after PT5 results are analyzed

Overview


Part Task 4
Integrated Basic (Minimum Information)
Integrated Advanced
Standalone Basic (Minimum Information)
Standalone Advanced
Integrated HITL
Advanced Information Only
Advanced Information + Vector Planner
Advanced Information + Auto Resolutions
Advanced Information + Trial Planner + Auto Resolutions
Part Task 5
Minimum Information
Stratway+ No Fly Bands
JADEM Fly/No Fly Bands
Vector Planner
Display Types:
Informative
Suggestive
Directive